

There are several other things we can do to reduce the internal seeing once the light reaches the delay-line and beam combination building. For example, the entire delay-line can be placed in a vacuum system. This is advantageous also from the point of view of differential dispersion discussed below, but is expensive and possibly difficult to deal with. An alternative is to use the “building within a building.” In this scheme the optical systems are placed within an inner enclosure, while the space between the outer and inner walls is air conditioned. The inner area is a large passive thermal mass and can remain stable for long periods of time.

6.6 Polarization

Each reflection from a mirror surface introduces a phase shift between polarization states. This means that the reflections used in each arm of an interferometer must be the same: reflection symmetry should not be broken. Reflection symmetry is also important in order to have the same image rotation in each arm. This normally means you end up with more reflections than you would like, but there is little one can do about this. For example, starlight passing through the central siderostat at COAST, shown in Figure 6.4, undergoes an additional two reflections so that its component s and p polarizations experience the same reflections as light from the other siderostats.



Figure 6.4: View of the array layout at COAST. The s and p polarizations of the light from each siderostat experience the same reflections prior to arriving at the beam combiner.

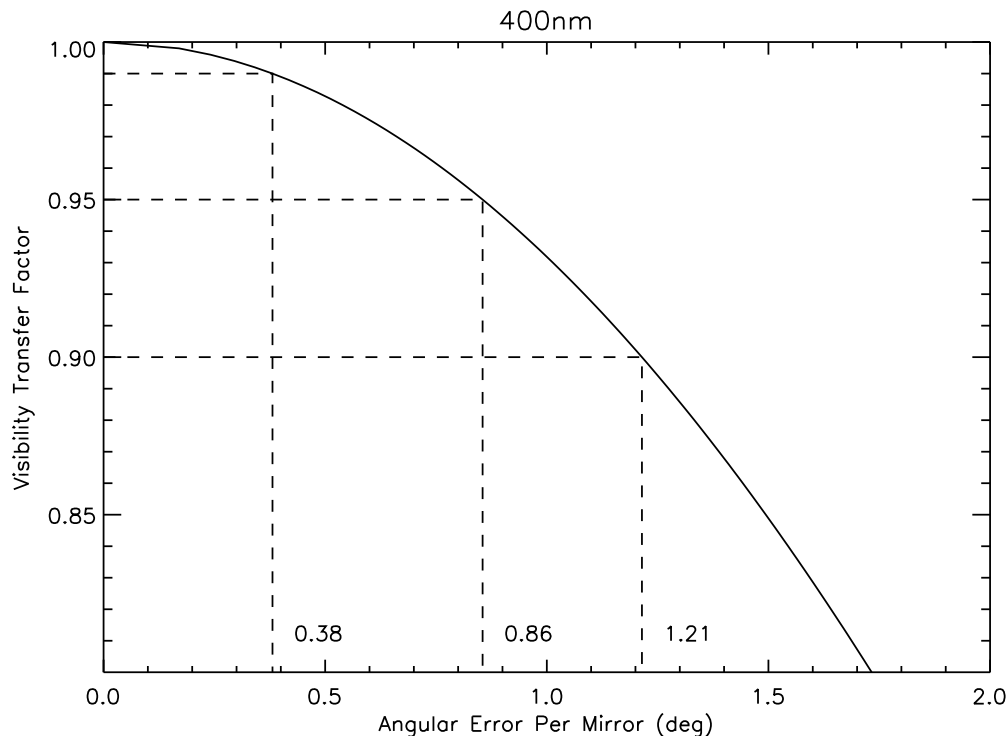


Figure 6.5: Plot of the visibility loss due to the phase difference between polarization states introduced by various differential reflection angles. Assumes 20 mirrors in each arm and is based on the work of Traub (1988).

The reflection angles in each arm must be kept the same to within quite small tolerances. If differential polarization-dependent phase changes are introduced into the different paths within an interferometer, visibility will be reduced. As an example of this effect, Figure 6.5 shows the visibility loss factor for a range of different reflection angle errors for a wavelength of 400 nm. In order to keep the visibility losses to less than 1%, the positioning of each mirror must be good to within a small fraction of a degree. Note that this figure is based on a polarization model, and the predictions of these models are often substantially different from real-world measurements.

One strategy for reducing errors due to polarization is to separate the two polarization states in the beam-combining area. For example, in the Sydney University Stellar Interferometer (Davis *et al.*, 1999) one polarization is used for the tip/tilt detection system while the other is used for the visibility measurement. Alternatively, one could use one polarization state for fringe tracking and the other for fringe measurement. A danger here is that there will be a small phase difference between the s and p polarization states, even if the reflection paths are symmetric, so that the centers of the fringe envelopes will not be in the same location.

6.7 Internal Optical Quality

Clearly the quality of the optics within the interferometer will have a significant effect on the measured visibility amplitudes. Each optic within the system will introduce a phase variance into the beam, reducing Strehl and also visibility. One normally assumes that these phase errors are random and add in an rms way. However, if all mirrors are made by the same process, this may not be true. Nevertheless, the internal image quality is relatively easy to measure and therefore calibrate.

A second important area of consideration when specifying the internal optics is optical throughput. There are often as many as twenty, or even more, reflections in an interferometer and each one contributes to signal loss. Coatings with reflectivities as high as 0.98 are available, but $0.98^{20} = 0.67$. Furthermore it is highly unlikely that these mirrors will stay this reflective; dust will always gather, and the light you do finally get to the back end of the instrument will be further divided into various subsystems. It is not uncommon to have as little as 5% or less of the light that enters the system go towards a scientific measurement. Another problem with some of the more fancy optical coatings is that they can have serious polarization effects. Plain silver or aluminum coatings seem to be the most common.

It may be possible to use an adaptive optics system to correct the internal image quality. In fact this may be one of the first applications for adaptive optics in interferometry. The deformable mirror can be set once using high intensity light from an internal source and held in position while the stellar light is sent through the system.

6.8 Diffraction

The long paths required in an interferometer imply that diffraction effects are almost unavoidable. Differential paths must be introduced to compensate for the external path introduced by the projected baseline and therefore differential diffraction will result in reduced visibilities (Hrynevych, 1992). Any beam reduction will make these problems worse. Furthermore, the combination of atmospheric turbulence and diffraction is not well understood.

In the case of differential diffraction, one must either rely on the calibration object, or re-image the input apertures within the beam combiner. The former assumes a relatively stable system and atmosphere. The latter is preferable but very hard to do.

6.9 Dispersion

There have been numerous studies of dispersion effects in stellar interferometry (eg. Tango 1990; ten Brummelaar 1995; Lawson and Davis 1996; Davis *et al.* 1998). The problem here

is that unequal path lengths within the instrument through vacuum, air and glass result in differential dispersion and thus a reduction in visibility. In fiber-based systems dispersion is a more serious problem, and it is therefore essential to use fibers of carefully matched lengths.

Dispersion is relatively easy to model approximately, although more difficult to model accurately. Compensation for dispersion can be done over a modest bandwidth using glass wedges. However, even with vacuum delay lines and a correction system, dispersion makes it very important to have a calibrator object as close as possible to the science target so that any dispersive effects will be the same in both measurements.

6.10 Controlling the Beast

Clearly an interferometer requires a very complex real-time control system, and the necessary software and hardware are by no means trivial. Most existing interferometers use a distributed control system and a mixture of real-time and non-real-time operating systems. In this way, individual subsystems and their controllers can be developed and tested in isolation. They are then linked together using some form of master control computer and user interface.



(a)



(b)

Figure 6.6: Well trained sequencers: (a) W.J. Tango at SUSI, (b) R.C. Boysen at COAST.

One of the most difficult aspects, apart from actually making each device function, is connecting them all together, sequencing, and error recovery. In most existing systems, apart from a few notable exceptions, the sequencer is a well trained observer, and error recovery depends on the knowledge this observer has of the system and its parts.

It has not been uncommon for the control code, and user interfaces, to lag behind the hardware in the development of an interferometer. The importance of starting control code development early in the design process cannot be overlooked.

6.11 Conclusion

There is of course no single or correct way to build an interferometer, but it is true to say that all of those built so far have many common elements, as is shown by the interferometers illustrated in Figures 6.7 and 6.8. I will conclude then with a list of things you will probably find on a “vanilla” interferometer:

- It will probably be located on an existing observatory site.
- It will have baselines several hundred meters long.
- The light from the input apertures will be brought into the beam-combining laboratory using evacuated light pipes.
- The lab will be located downwind of the array if possible.
- There will be many tons of concrete and steel.
- The input apertures, which to date have usually been siderostats, will in future interferometers probably be large telescopes in a partially redundant array.
- The optical system will be symmetric.
- The facility will include a long building to house the delay lines for each telescope; the delay lines being either in long vacuum pipes or in air in a building-within-a-building.
- There will be at least a tip/tilt system, perhaps even a full-blown adaptive optics system, located (preferably) at the telescopes.
- The beams will be brought onto a single table and combined together, either pair-wise or all at once.
- Some system for measuring the differential delay of each pair of beams will exist.
- The beam combiner will include beam splitters and/or fibers, and the light will be divided up for use in various subsystems, for tip/tilt detection (which must be done as close as possible to the beam combiner), fringe tracking, and so on.
- The back end will also include a great deal of optics for alignment, including a laser, a pin hole, a white-light source, a theodolite, TV cameras of many flavors, and lots of small pieces of paper with targets.
- It will not be easy.

Acknowledgments

Photographs of the Sydney University Stellar Interferometer courtesy of John Davis. Figure 6.7(a) courtesy of Ken Johnston. All other photographs courtesy of Peter Lawson.